MODELING FUTURE EMISSIONS OF ATMOSPHERIC POLLUTANTS

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INTRODUCTION

In recent years, Federal, state, and local governments have shown increasing interest in studying air pollution, with particular emphasis on acid rain, visibility, and other pollution issues. To evaluate potential solutions to the problems at hand, considerable data and information must be gathered and examined: current levels and patterns of the dependent variables to be studied, potential future regulations and technologies, and expected levels of emissions and control costs based upon future regulations and technologies.

For air pollution, the five dependent variables of interest are typically emissions, atmospheric transport, deposition, effects or damage, and costs of control. Computer models have been developed that can predict the levels or patterns of these dependent variables for several years or decades into the future based on historical or current input data and information about other factors that may affect the level of the five variables of interest. These models vary in their purpose, their level of detail, their costs of development and use, and their capability to analyze the effect of alternative levels of various factors on the dependent variables. The usefulness of computer models, regardless of their composition, lies in their ability to examine the effects of alternative assumptions about independent variables on the dependent variables without requiring the model user to do all necessary recalculations by hand.

Several factors distinguish one model from another; such factors include the general structure of the model, the level of model detail (usually inversely related to the time frame over which the model makes its predictions), and the user-friendliness with which the model operates. In general, policy analysts use two structural types of models to make forecasts of future activity levels: econometric and engineering or process models. Econometric models use historic data and relationships to estimate future trends in variables of interest. Engineering or process models use the physical relationships of production processes (i.e., the relationship between inputs to a production process and its outputs) to predict levels of the dependent variables.

This paper selects one engineering/process model, the Environmental Trends Analysis Model II (ETAM II), and describes the methodology used to forecast emissions of a number of air pollutants from the electric utility sector. ETAM II uses exogenous activity level information (i.e., supplied from outside the model rather than produced within it), to which production relationships are applied as a means of generating estimates of pollutant emissions. ETAM was originally developed to provide environmental trend analyses in support of the U.S. Department of Energy's (DOE) 1983 National Energy Policy Plan (NEPP). Since then, it has been updated with modified algorithms and additional capabilities and new data have been added; the resultant model is known as ETAM II. ETAM II has been used for policy and sensitivity analysis in support of such programs as the Interagency Visiblility Task Force and the Interagency Prevention of Significant Deterioration Task Force.

ETAM II and the methodology it uses to forecast electric utility emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are described in this paper. In addition, a brief comparison of the emission forecasting technique used in ETAM II and those used in other models is given. Also included are sample results from ETAM II.

ETAM II METHODOLOGY

Introduction

ETAM II is a generalized forecasting system that can be used to project a variety of environmental indicators: 21 air pollutant species, 2 water pollutants, water withdrawal and consumption, 4 types of solid waste, and 5 measures of radiation. ETAM II is unique in that it both covers numerous residuals (i.e., emitted or discharged air, water, or solid waste pollutants) and all economic sectors discharging those residuals and is easy to use for policy analysis purposes. ETAM II is capable of measuring the indicators identified above from eight source sectors: electric utilities, industry, residential and commercial sources, transportation, agriculture, mining and minerals, synthetic fuels, and other sources. The "other" category includes sources such as forest fires and dust rising from gravel roads. Projections for the air, water, and solids pollution indicators can also be disaggregated by Federal region and energy use category (i.e., related or unrelated to energy production activities).

ETAM II is designed to be a scoping model, that is, a model that will provide quick results based on a number of different input assumptions. The model does not provide a great level of detail; for example, forecasts are made at the Federal region level of detail (the 50 states being aggregated into ten Federal regions) at 5-year intervals to the year 2030. Emission estimates are also available by end use sector and by industry type. Other models are available which, although providing more detail, such as electric utility plant or electric generating unit-specific emissions on a monthly or yearly basis, may not make forecasts so many years into the future or may be more difficult to run in terms of evaluating the effects of alternative input assumptions.

ETAM II also has been designed to allow users, even those with little or no computer experience, to make runs. For those interested users with a minimal amount of programming experience, the computer source code (i.e., the commands that constitute the model) can be altered to allow more complicated changes in input assumptions.

Data Sources and Methods

A number of external data bases and models have been incorporated into ETAM II, either in full or in part. These include the National Acid Precipitation Assessment Program (NAPAP) inventory of non-utility emissions (1), the electric utility Unit Inventory (2), the FORECAST electric utility emissions model (3, 4), data from the Residuals Accounting Model (5), DOE's NEPP (6), and DOE Secretary Hodel's testimony before the U.S. House of Representatives (7). In addition to the exogenous driving inputs listed above, ETAM II accepts a number of user-specified assumptions which affect its results. These are discussed in greater detail in the two volumes of ETAM II documentation (8, 9).

Utility Methodology

In general, ETAM II uses input data to estimate electricity generation in future years. Emission factors and the effects of alternative regulatory scenarios are then used to estimate the discharge of various environmental residuals. Alternative levels of economic or energy price growth affect emissions because economic factors and energy prices affect the demand and supply, and therefore the generation, of electricity.

The electric generating Unit Inventory (2) is a key component of the projection process. It contains generating unit-specific data on unit type, size, age, capacity factor, emission rate, and fuel use. The model compiles these data by state and then derives certain summary statistics -- for example, the ratio of baseload to peaking capacity and the mix of fuels used in peaking generating units. The user of ETAM II, when running the utility component, provides input information on the forecast horizon, coal plant lifetimes, coal plant capacity factor, and environmental regulations (9).

ETAM II updates the 1980 generating Unit Inventory in 5-year increments. For each increment, SO_2 emissions from existing generating units are reduced to meet air regulations (i.e., State Implementation Plan targets). Generating units are retired according to announced retirement dates (10) occurring within each 5-year increment. If no retirement date has been announced, generating units are retired (after 1991) according to default retirement dates linked to plant lifetimes. Emission levels are further reduced to reflect these retirements.

Announced plans (10) to convert oil-fired capacity to coal are assumed to occur as scheduled. Additional conversions are assumed to occur in 19 states. Emission levels are increased to reflect these conversions.

If the user has so specified, ETAM II then adjusts the capacity factors of existing generating units. The capacity factors of oil and gas-fired generating units can be reduced to implicitly reflect their high fuel costs. The capacity factor of coal-fired generating units can either be increased to reflect utilities' success in efforts to reduce unusually high reserve margins or be decreased to reflect lowered availability as equipment ages. All generating units of a given fuel type are affected when an adjustment is made (i.e., the capacity factor of all existing coal-fired generating units, regardless of age or location, would be raised or lowered to the specified rate). Emission levels are adjusted accordingly.

National average growth rates for electricity demand, specified in the NEPP projections, are allocated to each state according to the ratios implied in 1980 North American Electric Reliability Council (NERC) forecasts. Within each state, demand is partitioned into baseload and peaking segments, using the state's 1980 ratio of baseload capacity to peaking capacity. This ratio is assumed to remain constant throughout the projection period. The fraction of total demand that can be accommodated by existing generating units is subtracted, and any remaining demand is assumed to be satisfied by new baseload or peaking generating units, depending on which segment is unable to meet demand.

New generating units are added according to the on-line dates specified in NERC's announced generating unit list and are assumed to operate at the default new unit capacity factors. The model will defer announced generating units in a particular state if they are not needed to meet the demand derived from NEPP. The new coal-fired generating units are assumed to comply with current revised New Source Performance Standards (NSPS) or Prevention of Significant Deterioration regulations, depending upon which are more stringent, or alternative regulations if specified in the input assumptions.

If a state's electricity demand is not met after all announced generating units have been put on-line, the model sites additional new generating units in the state to meet projected needs. The following assumptions are relevant to this decision:

- each state's 1980 ratio of baseload to peaking capacity remains constant;
- all additional baseload generating units built after the NERC announced generating unit list is satisfied but before the year

2000 are assumed to be coal-fired (except in California, where all new capacity is assumed to be from renewables);

- 80 percent of new baseload generating units built after the year 2000 are assumed to be coal-fired and 20 percent nuclear (except in California, where all new capacity is assumed to be from renewables);

- each state's 1980 mix of fuels used in peaking generating units remains constant; and

- new generating unit emission standards apply.

NEPP projections of utility sector fuel use are applied as "control totals" on ETAM II's initial calculations for each projection year. ETAM II determines each state's share of oil, coal, gas, nuclear, and alternative fuel use for 1980. ETAM II then uses these shares to proportionally disaggregate the NEPP national totals for each projection year to yield fuel-specific subtotals for each state. The NEPP subtotals available by fuel are then used to calibrate ETAM II's calculated subtotals by fuel and state. In effect, ETAM II makes marginal adjustments to the capacity factors of each generating unit (new and existing facilities) of a given fuel type in a particular state so that the model's fuel use totals equal the NEPP control totals. Emission levels are then adjusted in proportion to the fuel use adjustments.

The above methodology applies to forecasts made to the year 2010. For projections to 2030, each computational step is conducted in the same manner. Two differences should be noted: 1) the projection proceeds in 10-year increments so that each set of calculations combines the calculations for two increments in the 1980 to 2010 projection; and 2) the trends for the last 5-year increment (2005 to 2010) are extrapolated for the period 2010 to 2030. For example, capacity factors are assumed to remain at their 2000 level. ETAM II derives national-level electricity demand from NEPP and assumes state-level trends will continue linearly at the 2005 to 2010 rate. Note that for these longer-term projections, assumptions regarding plant lifetimes and emission standards become increasingly important.

ETAM II is unique because, due to its simplicity and structural design, it can be used to examine a number of alternative scenarios in a relatively short period of time. Scenarios examined can include the effects of different coal plant lifetimes, future environmental regulations, and energy and economic futures. By combining scenarios that result in high or low levels of residual discharge, ETAM II can provide its user with a range of emission levels, thus providing information about uncertainty in future residual discharge levels.

COMPARISON WITH OTHER MODELS

A number of other computer models are available for making predictions of pollutant emissions from electric utilities. These models include the Advanced Utility Simulation Model (AUSM), the National Coal Model (NCM), and the Optimization Model for Emission Generating Alternatives (OMEGA). Table 1 summarizes the relevant features of each of these models.

Advanced Utility Simulation Model

AUSM, sponsored by the U.S. Environmental Protection Agency in support of the National Acid Precipitation Assessment Program, is designed to project electricity demand, generation, and associated emissions. Considerable detail is included in the model in several areas, enabling in-depth analysis of the effects of various legislative scenarios. AUSM combines econometric modeling techniques

Table 1

Electric Utility Residual Discharge Models

Model	Program Type[a]	Regional Detail	Forecast Period	Residuals[d]	Developer[e]
AUSM	P, E	state	to 2009	TSP, SO_2, sulfate	EPA, URGE
ETAM II	P	10 Federal Regions	to 2030	TSP, SO_2, sulfate, NO_x, VOC, others	DOE, EHPA
NCM	P	state[b]	to 2010	TSP, SO_2, NO_x	DOE
OMEGA	P	state[c]	to 1995	SO_2	CMU

[a] P = process/engineering; E = econometric.

[b] NCM has 31 coal supply regions and 40 demand regions which approximate states in most cases.

[c] OMEGA uses 19 supply regions and 47 demand regions in a 31 state area.

[d] TSP = total suspended particulates; VOC = volatile organic compounds.

[e] EPA = U.S. Environmental Protection Agency; URGE = Universities Research Group on Energy (Public Policy Program, University of Illinois); CMU = Carnegie-Mellon University; EHPA = E.H. Pechan & Associates, Inc.

with process modeling techniques, resulting in a more complicated internal structure than that of ETAM II. AUSM's coal supply module contains distinct representations of coal costs and availability. The primary utility information data base used by AUSM has detail at the electric generating unit level. An annual recursiveness feature, which allows the projected price of electricity in one year to be reflected in the demand for electricity in the following year, is used in an econometric portion of the model to forecast electricity demand. A separate module within AUSM calculates control costs associated with any particular legislative alternative examined.

AUSM uses an extensive amount of input data. In addition to an inventory of generating units (the Unit Inventory) and an extensive file containing information on coal reserves and resources, a large quantity of input data must be specified by the user. Default values are available for these parameters, but a user needs to have some notion of appropriate values.

AUSM requires two user-specified scenario input files. One of these provides global parameters (e.g., inflation rate, flue gas desulfurization minimum size, etc.) and the other provides state-specific parameters (e.g., state emission limits, land use costs, etc.). In addition to these global and scenario parameters, each of the analysis modules within AUSM has a series of inputs which must be user-specified. The electricity demand module, for example, requires state-level forecasts of fuel prices, population, and economic activity indicators (i.e., personal income, earnings, and employment). The AUSM coal supply module requires the user to specify escalation rates for coal production costs at the mine-mouth and the costs of mining and cleaning coal (broken down by wages, capital costs, etc.). A separate module forecasts coal transportation costs, which can be up to 70 to 80 percent of the delivered price of coal.

Outputs from AUSM are more detailed than those from ETAM II and include state-level information on generation, peak load, prices, capacity additions, emissions and generation of residuals, coal use, and utility financial statements. Projections are made for 20 years into the future.

National Coal Model

NCM, sponsored by the U.S. Department of Energy for use in short and mid-term forecasting, is used to ascertain the impact of legislation on the coal and electric utility industries and to project coal production, consumption, and prices. The NCM is a process model that requires an extensive amount of data including information on utility operations costs, emission limits, capacity factors, coal demand and production, price and use of alternative fuels, and emission control costs. Outputs include coal production, transportation, blending, and consumption; generating capacity utilization; pollutant emissions; capital expenditures; and transmission of electricity. Each of these outputs is available by NCM region (approximately equal to state-level) and by Federal region to the year 2010. Proprietary variants of NCM are offered by some firms.

Optimization Model For Emission Generating Alternatives

OMEGA, a process model, was developed at Carnegie-Mellon University and examines emission control strategies of domestic coal-based electric utility plants. The current version examines only coal plants in a 31-state Eastern region. Due to its structure and computational algorithms, OMEGA is limited in the number of plant types, modes of transportation, coal types, and so forth that it can handle. The model is driven by an explicit listing of expected coal-fired startups from DOE's Generating Unit Reference File.

Required inputs to OMEGA are extensive and include coal-fired generation, use of coal by utilities, escalation rates for transportation costs, coal prices, coal production, capacity factors, plant lifetime, discount rate, emission reduction target, and method of emission allocation among states. Model outputs include emissions and control costs at the state level to 1995.

SAMPLE RESULTS FROM ETAM II

To provide an illustration of the type of ouputs provided by these models, the results in Figure 1 are based on the examination of alternative coal plant lifetimes by ETAM II. Figure 1 shows a comparison of assumed 40 and 60 year utility plant lifetimes on emissions to 2030. As can be seen, these assumptions have no effect on emissions from non-utility sectors, but have a tremendous effect on both the pattern and the level of total emissions.

The significant impact of a plant lifetime assumption is due to the stringent controls placed on new plants through NSPS requirements; with earlier retirement of plants, the newer and more stringently-regulated plants come on-line much sooner. For SO_2 emissions, the assumption regarding coal plant lifetime affects the year in which industrial emissions become the primary contributor to total emissions. Under the 40-year lifetime assumption, utility SO_2 emissions fall below industrial emissions by 2010. If a 60-year lifetime is assumed, this switch will not occur until about 2030.

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Figure 1. Coal Plant Lifetime Scenario Results

(40 versus 60 year plant lifetimes)